3S2–Behavioral Response Studies of Cetaceans to Naval Signals in Norwegian Waters

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LONG-TERM GOALS

The long term goal of this international cooperative research program is to investigate behavioral reactions and the sound exposures required to elicit them of herring, killer whales, pilot whales and sperm whales to Low Frequency Active Sonar (LFAS) and Mid Frequency Active Sonar (MFAS) signals, in order to establish safety limits for sonar operations for these species. The hypothesis that we are exploring in our current research program is that the large difference in hearing sensitivity of killer whales at the two sonar frequencies influences their behavioral reactions. Killer whale hearing is thought to be >25dB less sensitive at 1-2 than at 6-7 kHz. Exposure levels analyzed relative to this curve in fact reveal that the "sensation levels" of the 6-7 kHz sonar at the time of the behavioral change in fact exceeded those of the total 1-2 kHz exposure. The term "sensation level" refers not to absolute intensity of a sound, but intensity relative to the hearing threshold for that sound for a given individual. Acoustic criteria recommend use of sensation level to estimate physiological impacts on hearing (Southall et al., 2007), but the specific influence of hearing sensitivity on the probability of *behavioral* effects has never been directly assessed. Our preliminary results do not support the hypothesis that killer whales are more sensitive to the MFAS than the LFAS sonar, as predicted by sensation level.

OBJECTIVES

The primary objective of this project is to quantify the exposure levels required to elicit behavioral reactions of cetaceans (killer whales, pilot whales and sperm whales) and herring to controlled presentations of military sonar signals at 2 different frequencies (LFAS:1-2 kHz and MFAS:6-7 kHz), and relevant control sounds within Norwegian waters. These data will be used to help establish safety limits for sonar operations. A second objective of the research program is to continue to monitor the movements and behavior of killer whales in relation to future FLOTEX naval exercises, if possible. The project is motivated both by the applied need to assess the environmental impact of a new lower-frequency sonar system and the basic science question of the influence of sonar frequency on behavioral effects on marine mammals. We have an objective of testing the prediction that the aversiveness, or behavioral impact, of a sound should be influenced by the hearing sensitivities of species at the relevant sonar frequency.

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APPROACH

Our primary approach is to conduct controlled presentations of military sonar signal sequences in blocks at 2 different frequencies (1-2 kHz and 6-7 kHz), and relevant control sounds, while observing the behavior of whale subjects using tags, towed hydrophone arrays, and visual observations. Specific research tasks are: 1) Determination of behavioral response thresholds by approaching a tagged whale while transmitting sonar signals. Each tagged whale is sequentially tested at both sonar frequencies, in random order, with no-sound approaches or playback of killer-whale calls included as practicable as negative and positive controls*;* 2) Description of behavior during sonar exposures versus baseline and controls, and interpretation of the biological significance of any observed behavioral change. Careful monitoring and mitigation protocols are followed to reduce risk of harm to all research subjects; 3) Exploration of how response thresholds vary at different sonar frequencies, and in relation to reported hearing thresholds at the tested frequencies. Because we have better data on hearing sensitivity for killer whales, they have been the primary study species, but experiments with pilot and sperm whales enable a fuller comparative analysis of behavioral reaction thresholds across cetacea.

The research is carried out by an international collaborative team from the Woods Hole Oceanographic Institution (WHOI), Sea Mammal Research Unit (SMRU) of the University of St Andrews, Norwegian Defense Research Establishment (FFI), Institute of Marine Research (IMR), and Netherlands Organization for Applied Scientific Research (TNO). WHOI is providing scientific advice from Dr. Peter Tyack, field involvement of Alessandro Bocconcelli, as well as the provision of Dtags and Dtag technical support. SMRU is home to PI Patrick Miller. Project management and logistic support, including acquisition of research vessels and permitting are managed through FFI, led by Dr. Petter Kvadsheim. FFI also provides biological and tagging expertise, including the development of a new pneumatic launching system for the Dtag, in a collaboration between Lars Kleivane of FFI and Alessandro Bocconcelli of WHOI. TNO contributes an advanced towed array system for recording and detecting marine mammal sounds (Delphinus), a multi-purpose towed source (Socrates), and staffing during the cruises under the leadership of Frans-Peter Lam, with collaboration from René Dekeling of the Royal Netherlands Navy. The Socrates source system is capable of transmitting 1-2 kHz signals at a source level of 214dB re1µPa @1m, and 6-7kHz signals at a source level of 199dB re1µPa @1m. IMR provides scientific advice related to the presence of fish, primarily herring, prey of killer whales and other marine mammals.

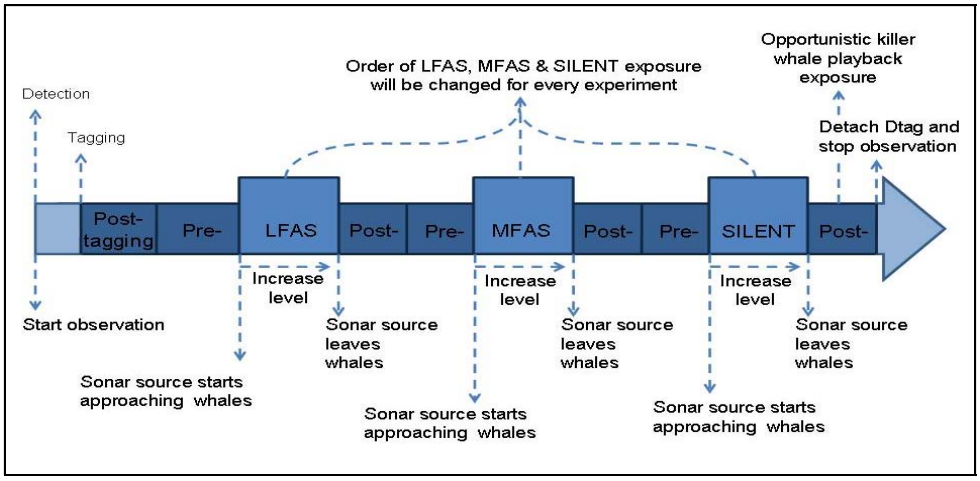

Figure 1. The different steps in the multiple stimulus presentation used in the 3S experiments.

The experiments involve a sequence of phases, from searching for potential subjects, to tracking a focal group, to tagging, playback, post-playback observations and recovery of the tag. During the search phase, observation teams on both ships conduct visual surveys and both towed hydrophone arrays are deployed to listen for cetacean sounds. All visual sightings are recorded in Logger, and acoustic detections are recorded by system-specific software. Upon acoustic detection of a target cetacean, the vessel is maneuvered in the direction of the animals to obtain visual detection. Upon visual detection of a cetacean species that is a potential subject for the experiment, the observation team on board the observation vessel starts tracking the group. During tracking, the travel path, as well as individual and group behavioral parameters are monitored at a rate of 1 record per ~1.5 minute. Following 30 minutes of baseline data collection (pre-tagging phase), one or both tag boats are launched from the source vessel to commence tagging with Dtags using either a pole, or the ARTS system for deployment. The tagging phase ends when one or two tags have been deployed, or the decision is made to leave that group. The following phase, the experiment, consists of a block design including LFAS, MFAS, killer whale sounds and silent approaches, including pre- and post exposure intervals before and after each block (see Figure 1). During the experiment, the observation vessel stays in good sighting range of the tagged animal for tracking, while the source vessel is positioned following a predetermined protocol for the transmission of sonar sounds to the tagged animal and maneuvers accordingly. The playback protocol calls for positioning the source vessel about 4 nmi away from the subjects. The initial course of the source ship upon start of transmission is determined based on a visual fix before the start of transmission. The ship then approaches the subjects at a speed of 7-8 knots, adjusting course to head towards later sightings of the whales. It ramps up the source level of the source and then continues to approach with the source at maximum level. During the tracking of sperm whales, the individuals are tracked acoustically during dives and these acoustic locations may also be used to direct the ship with respect to the whales. Once the source ship is 1 km from the whales, it maintains the same course and transmits until the standard end of the transmission sequence. The goal of the playback protocol is to conduct a silent playback, MFAS and LFAS in a random sequence to each animal. If there is time, this may be followed by a killer whale or other playback. The 3S09 cruise was also able to test a new protocol designed to test the efficacy of ramp-up. Following the release of the tag(s), both ships return to searching phase and data checking/processing.

WORK COMPLETED

Data collection was completed for this project in the summer of 2009, and the past year was primarily spent on data processing and analyses to achieve the project objectives. Data processing entails database construction, basic calibration and groundtruthing of tag data, and the creation of descriptive plots and summaries of the experiments. The two primary data analyses required are acoustic analyses of the sonar dose, and behavioral analysis of responses to the sonar. Once both dose and response data are quantified, our plan is to combine these into dose-response relationships. We have now completed the data processing for all of the experiments, including tag calibrations, acoustic audits of biological sounds on tag recordings, and database construction. We have also completed the analysis of all received levels of all sonar pings that arrived on Dtags or arrays of hydrophones towed near the whales. Finalization of the received levels entailed calibration of the Dtags and towed array at TNO and in the field. This basic level of processing allows for a detailed examination of the datasets, and the ability to identify changes in behavior that could have been caused by the sonar. We have initiated production of a technical report to bring together the diverse pieces of information on the sonar levels

as well as the whale behavior, movement, diving, and sound production. The report is largely complete for all of the 3S experiments, including experiments conducted in 2006.

In addition to the broad effort of organizing the substantial 3S dataset, we made significant progress over the last fiscal year on the project goals for killer whales. Though we conducted the sonar exposure experiments in precisely the same fashion for all three of our target species, our killer whale dataset is quite different from that of the other two target species (long-finned pilot and sperm whales). These differences are: 1.) killer whales are the only species for which we have audiogram data over the range of both 1-2 and 6-7 kHz data; 2.) we were able to monitor killer whale presence in Vestfjord during the 2006 FLOTEX trial; and 3.) because of substantial whale-watching effort to find killer whales in Vestfjord, we have been able to conduct a retrospective analysis of whale presence in relation to sonar activity in the fjord. To link our experimental data with whale presence in Vestfjord during the FLOTEX trial, we focused our analysis of how killer whale movement changed during our controlled experiments. The results of the playback experiments are quite striking, with clear indications of avoidance during 6 of 8 total exposures. The dose-response analysis of killer whale avoidance is now complete, and we have combined those results with our observational results from FLOTEX 2006 and the retrospective study. The manuscript stemming from this work will be submitted early in the next fiscal year.

RESULTS

Dataset: The combined 3S cetacean CEE data set totals 4 killer whales, 4 sperm whales, and 6 pilot whales, and is well-balanced in terms of sonar frequencies presented to the whale. Three of the pilot whale exposures were to animals that were likely present nearby during prior experiments, so should be treated somewhat differently from the exposures to 'naïve' individuals. We have also achieved 14 playbacks of natural killer whale sounds (*orca*), including 2 that were completed during the baseline research trial in Iceland and 4 during the 2010 baseline trial in Norway. Baseline data to better describe the natural behavior of the study species and to make statistical comparisons to the experimental datasets (see Miller et al., 2009 for an example of incorporating baseline data into CEEs) was collected in this fiscal year under award number N000141010355.

Analysis of received levels: Our analysis of received level recorded at the whale for each sonar transmission is now complete. We have achieved highly satisfactory matches between the levels measured from tags and the hydrophone arrays towed nearby. We feel that our received level measurements are accurate to ±5dB, but some shielding of the signal by the body of the whale appears to occur in some cases. The analysis demonstrates that the 3S protocol of approaching the tagged whale enabled us to expose the animals to fairly high sonar levels (Fig 2), of relevance to US Navy management needs.

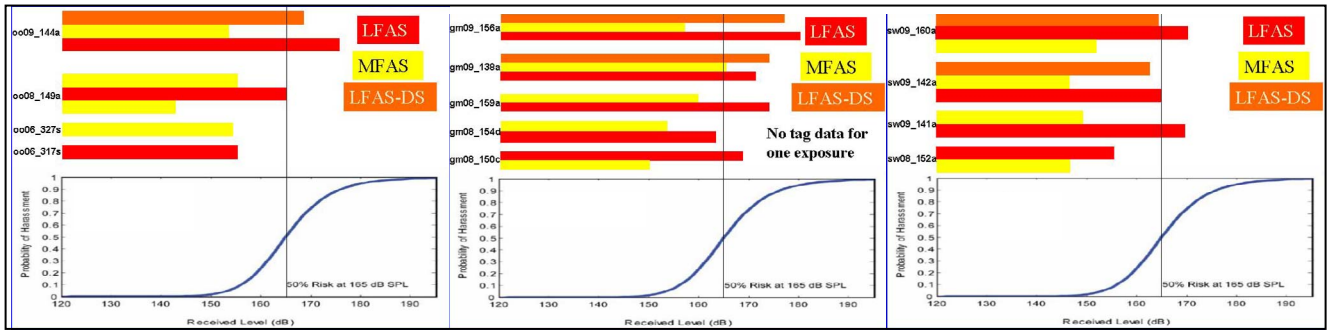

Fig 2. Highest received sound pressure level (SPL in dB re 1 µPa) averaged over 200ms for experiments with killer whales (left), long-finned pilot whales (middle), and sperm whales (right). Each experiment tag deployment is labeled on the left of each colored line, and the type of sonar exposure is shown by color. The dose-response curve below each histogram is the harassment dose-response curve currently used by the US Navy for preparation of environmental impact statements. Our experiments cover most of the exposure range where the probability of response is predicted to change.

Data processing and integration: For each data record, we record 3 primary behavioral data sets: Dtag data, surfacing location to form a track, and group-level behavioral sampling. To this record, we must combine the location of the source vessel and the source level of all transmission, as well as the location and transmissions from the killer whale playback boat. The Technical Report combines these data streams for all of the 3S experiments. The primary means of presenting the material are GIS tracks and time-series data (e.g. Fig 3). The plots provide rich material to describe what occurred in each experiment, and form the background material for a peer-reviewed paper describing the different types of possible effects that we observed in our data. At this time, the report is largely complete, with the expectation that it should be finalized during 2010.

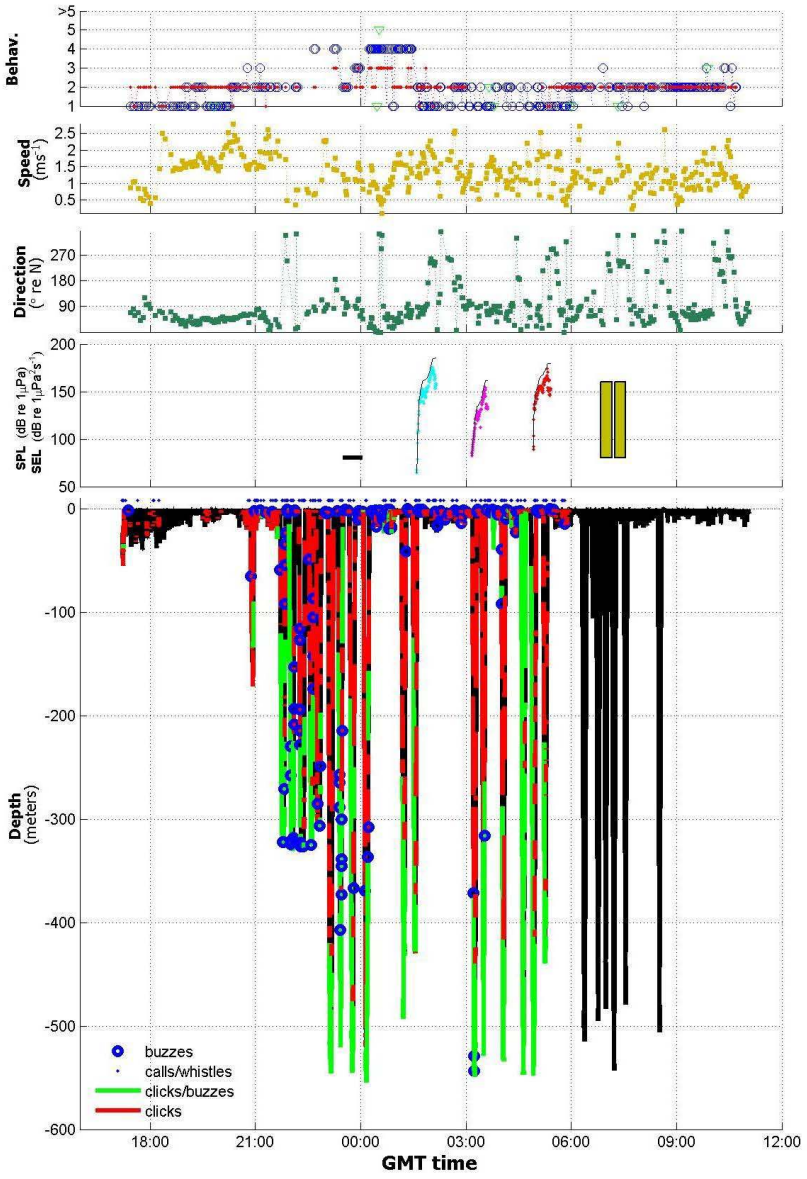

Figure 3. Time-series plot of subject long-finned pilot whale gm09_156a for inclusion in the 3S technical report. The top panel shows group spacing, synchrony and surface behaviors, 2nd and 3rd from top show horizontal speed and direction, respectively. The 4th panel shows exposure data, including received level for sonar transmissions. The bottom panel shows the dive profile with social sound indicated above the profile, and foraging click, buzz and tailslap sounds plotted on the profile.

Dose-response relationships in the killer whale: Avoidance reactions were observed in 6 of the 8 experimental exposures to killer whales. These avoidance reactions typically entailed increases in speed, change of direction or change to more directional movement, and movement sideways to the approach path of the source boat. We used the track data and detailed inspection of the Dtag record to specify the time when the reaction started. The highest received level before the reaction started was used as the threshold for the response. Taking advantage of the dose-escalation nature of our experiments, the results of all 8 exposures were combined to calculate the cumulative proportion of

groups responding as a function of received level. These proportions were fit to a logistic curve (Fig 4) which enables estimation of 134 dB re 1µPa as the received level at which 50% of groups are predicted to respond to sonar by commencing avoidance reactions.

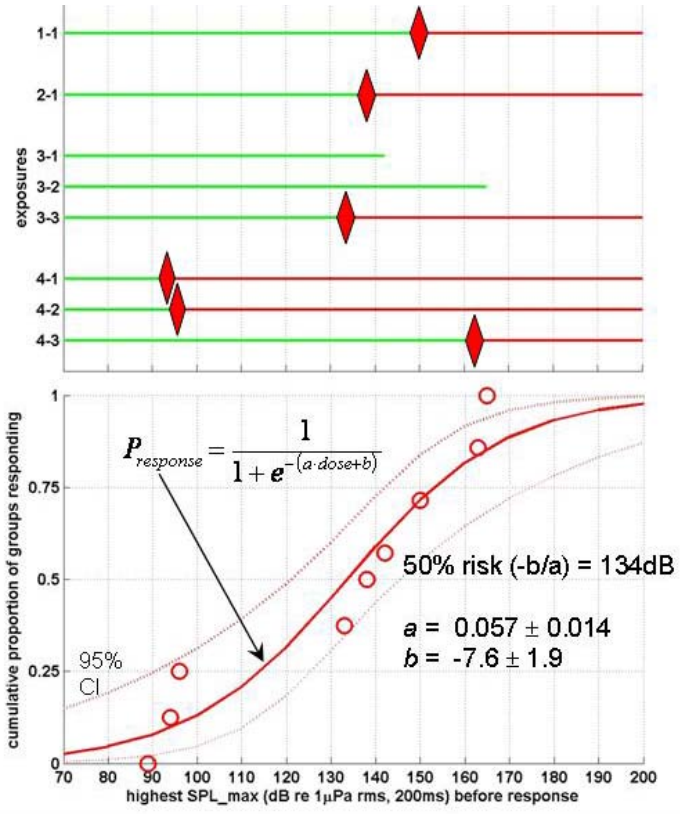

Fig 4. Top: experimental exposures to killer whales with each line indicating an exposure run. The red diamonds indicate the received level at which avoidance reactions were observed to start. Bottom: the cumulative proportion of groups that had commenced avoidance (red circles), and line fit using the logistic equation (shown in inset box). The parameter values for the best fitting logistic curve are shown, as is the 50% point which is easily calculated from the parameter values.

The dose-response method illustrated in Fig 4 is also a powerful tool for assessing whether predictability of responses is influenced by the hearing sensitivity of killer whales (Fig 1) with indications that weighting the received levels does not improve the steepness of the dose-response curve. The results of this dose-response analysis, combined with our observations during the 2006 FLOTEX trial and the retrospective analysis of whale-watch sighting in relation to sonar activity in Vestfjord has been prepared as a manuscript to be submitted soon for publication.

IMPACT/APPLICATIONS

The success of this project in achieving relatively large numbers of playbacks for several stimulus types and several species affirms the role of CEEs in effects studies. This project continues to build a strong international team, platform, and technology with excellent skills for developing and conducting studies on the effect of sonar on marine life. The results show little adverse effect of sonar on herring. The efficacy of using frequency or other acoustic parameters of sonar pings as a mitigation measure

can be tested by playbacks of various sonar stimuli. Differential responses or responses at different exposure ranges would suggest potential for mitigation. In the case of killer whales, our study does not suggest differential responses to LFAS vs. MFAS sonar signals.

RELATED PROJECTS

The 3S project involves a collaboration between the Norwegian Defence Research Establishment (FFI), Maritime systems, Norway, TNO Defense Security and Safety, Observations Systems, The Netherlands, the Sea Mammal Research Unit, University of St. Andrews, Scotland and the Woods Hole Oceanographic Institution, USA. The SMRU and WHOI efforts are supported by ONR, and the 3S project includes cost sharing from the Norwegian and Dutch navies. The ONR ARTS DTAG project (N00014-10-1-0380) stemmed from the collaboration between these partners in tagging highly maneuverable whales. The ONR projects Behavioral Response of Odontocetes to Playback of Anthropogenic and Natural Sounds (N00014-07-1-0988) and Tagging and Playback Studies to Toothed Whales (N00014-09-1-0528), the Naval Postgraduate School funded project "Dtagging and analysis of studies on effects of naval sounds on marine mammals in waters off southern California", the SERDP project RC-1539 "Acoustic Response and Detection of Marine Mammals on Navy Ranges Using a Digital Acoustic Recording Tag", the Naval Oceanographic Office funded project "Behavioral Response Study (BRS-07) Analysis and Supplemental Funding for BRS08" are all part of collaborative research programs that aim to study how tagged beaked whales respond to US mid-frequency sonar signals (~3 kHz) compared to control sounds, and to compare responses of beaked whales vs other odontocetes to playbacks of mid-frequency sonar sounds vs other anthropogenic signals. Ultimately these studies all aim to define dose: response curves for risk to beaked and/or other whales for exposure to naval sonars, and to suggest improvements for mitigation.

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